Visualizing Anatomical Structure in Secondary Education
and the Success of the Whole Frog Project
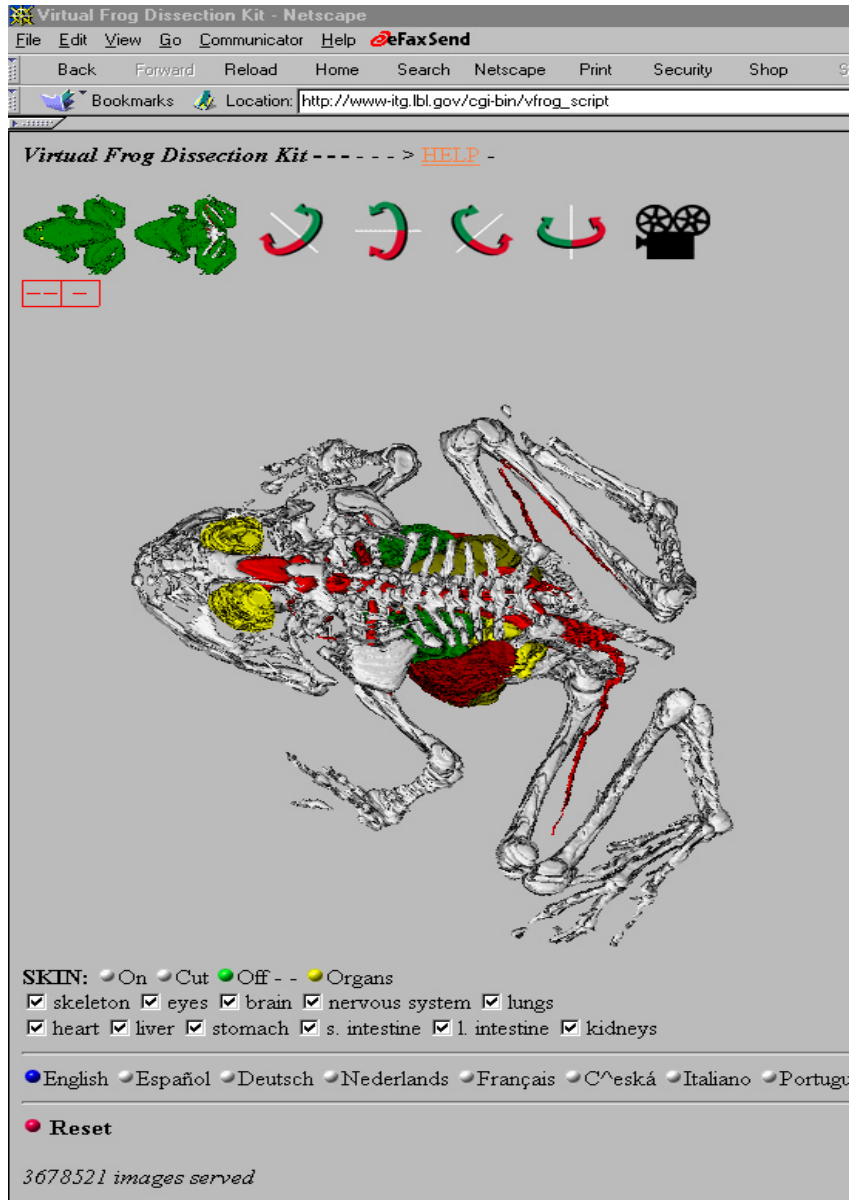
William Johnston[1] and David Robertson
Information and Computing Sciences Division, Lawrence Berkeley National Laboratory

Summary

The LBNL Whole Frog Project was initially intended to provide a prototype high school curriculum unit on computer imaging and 3-dimensional visualization that would demonstrate the potential of interactive computer exploration of data that represents the "real" world. The content of the project was determined by two groups of high school teachers who quickly settled on a frog as the object to be visualized. So, in the collaboration that developed the Virtual Frog Dissection Kit, the content was determined by the teachers and the technology (a network distributed visualization system and the first Web based interactive 3D interface - see [1]) were provided by LBNL. The result has been a Web based science education tool that is used by teachers and students all over the world. The user interface is available in seven languages, with the translations being provided by teachers who wanted students to have access to the Virtual Frog Dissection Kit in their native tongue. In the past several years some 3.5 million frog images and 150,000 frog movies have

delivered to more than 100 countries. (The users are about 66% US, 33% foreign, and 10-15% non-English, and overall about 50% from educational institutions - 1300 US Highschools are regular users.) This project does not currently provide enough material for a coherent curriculum unit, but it clearly demonstrates the potential of the approach.

History of the Whole Frog Project

The motivation and vision for this project date from 1992-93 (from [4]):

> Sophisticated image-based applications have the potential to play an important part in enhancing curriculum in a variety of disciplines, both cultural and scientific, and in providing K-12 students with the involvement and motivation to learn a wide variety of computer skills. An example of this is our "Whole Frog" project. In this project the idea is two fold: First, to demonstrate the utility of image based applications in biological sciences through a demonstration of whole body, 3D imaging of anatomy as a curriculum tool; and second, to introduce the concepts of computer based imaging, 3D geometry, and visualization.

> The curriculum goal of the Whole Frog Project is to provide high school biology classes the ability to explore the anatomy of a frog by using data from high resolution MRI imaging and mechanical sectioning, together with 3D surface and volume rendering software to visualize the anatomical structures of the original animal. Ultimately we intend to be able to "enter the heart and fly down blood vessels, poking our head out at any point to see the structure of the surrounding anatomy". The secondary goal of this project is to introduce the concepts of modeling and displaying 3D structures directly from 3D images obtained, for example, from MRI imaging (biological specimens), X-ray CT imaging (industrial imaging of non-biological objects), and direct generation from mathematical descriptions. Introducing this technology requires training teachers and students in the concepts and tools of image acquisition, enhancement, and analysis, and in the construction and manipulation of 3D graphical representations.

> The recognition of the potential impact of this technology on students grew out of our experience with undergraduate courses in computer graphics and image processing. The experimental study unit for biology was developed with the assistance of several high school teachers, and during the summers of 1991-92 we conducted an experiment to establish the parameters of a more extensive program. In this experiment we used a computer science graduate student to train two high school biology teachers in the use and concepts of the computer systems and tools needed to image and visualize 3D objects (initially an orange). These teachers were enthusiastic learners, and as they mastered the concepts they suggested modifications in the material and techniques that would be needed to introduce this material into the classroom.

> The whole frog project is an example of one class of exploratory imaging applications, other examples of this 3D imaging and visualization include a high resolution X-ray CT scan of a small jet engine, and 3D confocal microscope images of large uni-cellular organisms like Paramecium. Other classes of imaging applications that we have proposed for involving advanced imaging, computing, and networking technology in the secondary education system include a "digital darkroom" project, on-line access to earth image repositories (both the EROS Data Center and U. S. Sprint have expressed interest in this), and on-line access to museum image databases (for example U. C. Berkeley's Lowie Museum of Anthropology) [In 1997 EROS and Microsoft are now doing an on-line US image database, and many museums are, of course, also on-line. -WEJ]

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WEJohnston@lbl.gov
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> *We are currently developing the technology to bring an optical microscope on to the network in a way that permits remote control and manipulation, and display of live video output from the microscope.* [The technology for this has been developed as part of an ER/DOE2000, on-line instrument systems project. -WEJ]

> *At the present time, the available material includes a study outline, numerous images of the frog and several plants, the high resolution volume data sets and 3D models for various internal structures of the objects that have been studied, scripts and prescriptions for display and manipulation in several 3D visualization packages, a teacher produced MacroMind Director multimedia frog anatomy sequence, and several movies (in the form of digital image sequences, some of which have been transferred to video tape).*

Our initial approach - mostly as a result of our involvement with the LBNL (then) Research Medicine Division, and their high resolution MRI systems (see [5]), was to use a high resolution MRI scan of a human brain (actually Tom Budinger's brain) as the source of the data with which to demonstrate computer visualization. However, after working with a group of high school biology teachers and undergraduate biology students, the initial choice of a human brain as a data set was discarded because of its "non-intuitive" complexity.
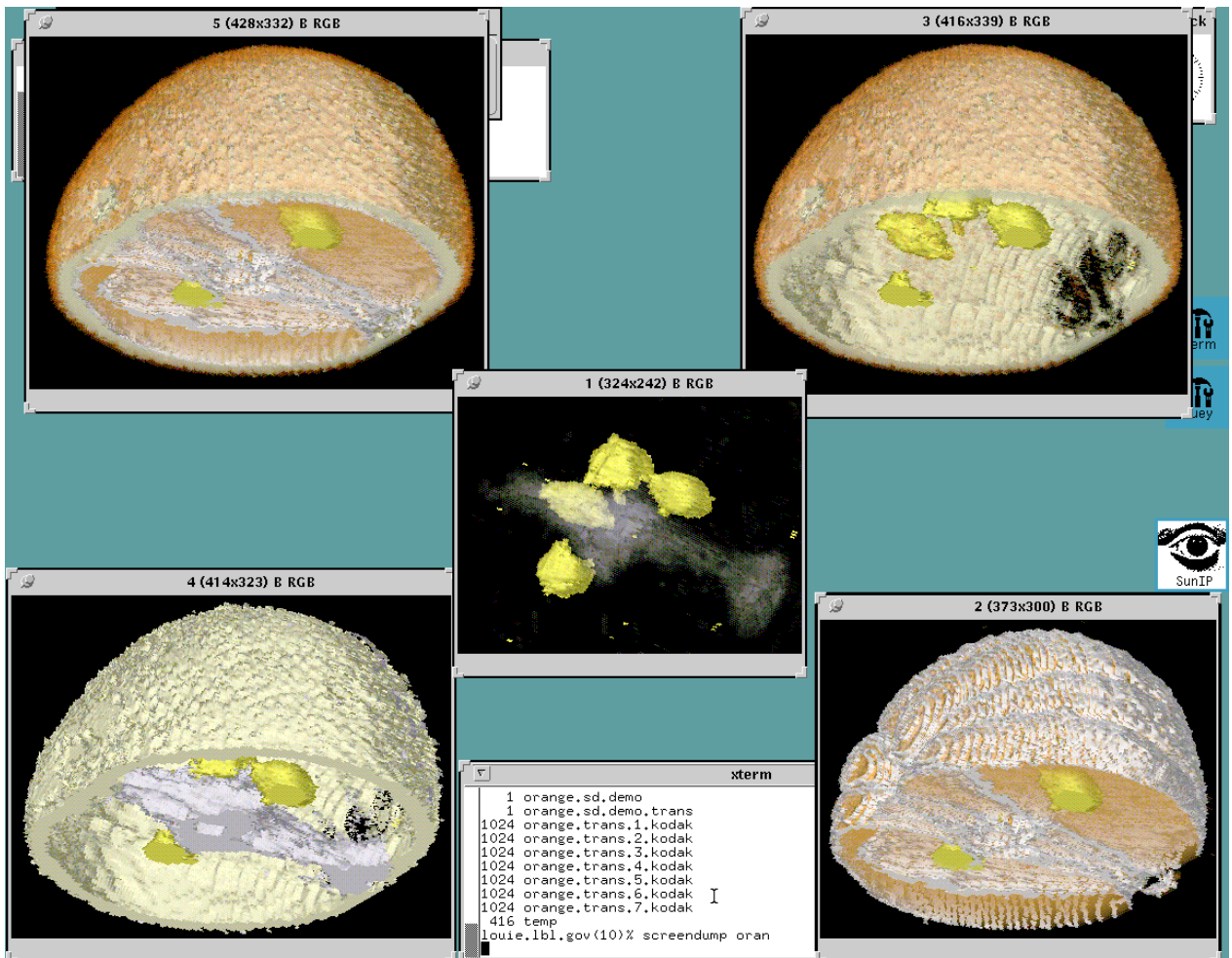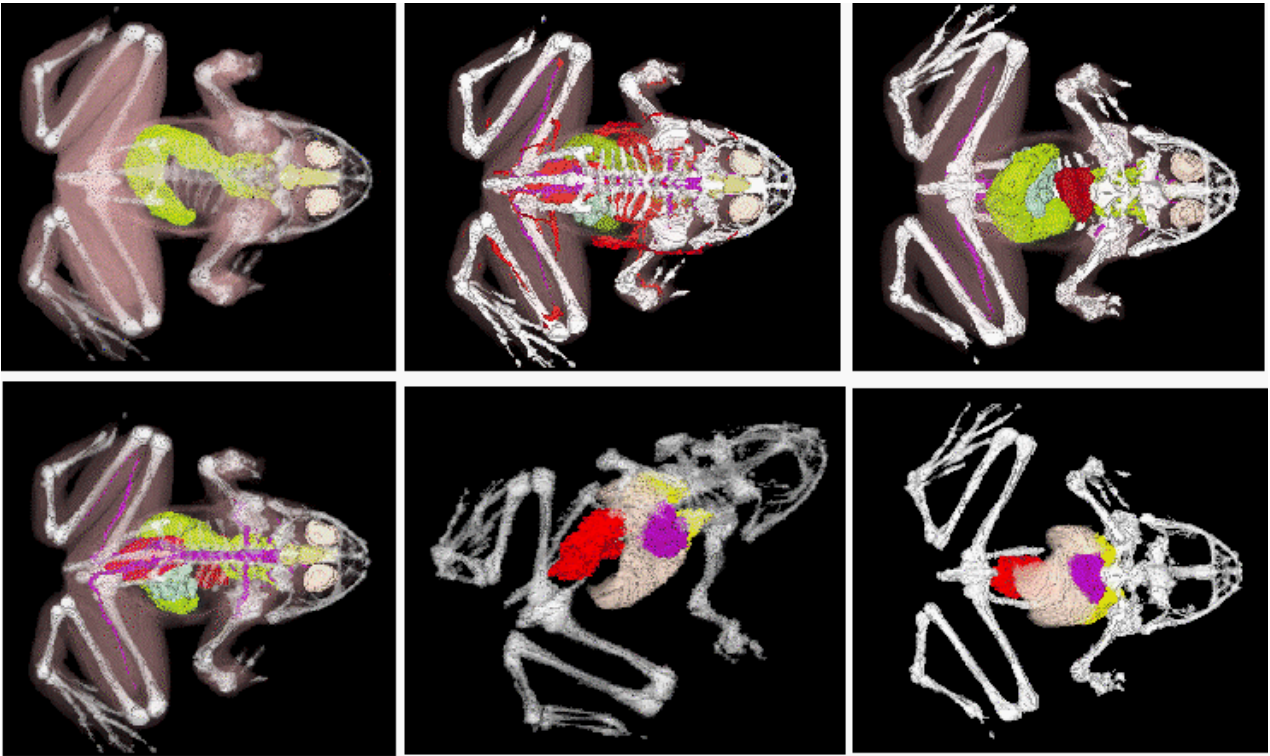
The consensus of the biology teachers and students was that a frog would be the ideal specimen, and so we built a high resolution 3D data set of the internal structure of a frog. The original vision of the project was to build a library of biological specimens, with the frog as the "flagship" example. We wanted to be able "enter the heart and fly down blood vessels, poking our head out at any point to see the structure of the surrounding anatomy." We never got quite that far, but we did produce a useful prototype with frog, orange, and tomato data sets.

Process

For the frog, several biology students spent a summer segmenting the slice images in order to define the 3D structure of about fifteen anatomical systems (blood vessels, brain, duodenum, eye, eye retina, eye white, heart, ileum, kidney, large intestine, liver, lung, muscle, nerves, skeleton, and stomach). The students and teachers then used this material to put together several multimedia teaching units based on frog anatomy as exhibited by a variety of computer visualizations. (See, for example, http://george.lbl.gov/ITG/Whole.Frog/frog/frog.anatomy.html). (This process is the same as NIH envisions for the "Visible Human" project [6].)

What became apparent during this process was that the real "payoff" of the project would be to allow students to directly interact with the 3D visualization process. However, the available visualization tools were too complex for students. Since the Web was becoming a well understood and capable mechanism (in 1993-94 the interactive capabilities of Web image-maps had just been introduced), we decided that the best way to provide simple interactive manipulation would be to use the Web as the front-end to provide the user interface for a 3D visualization system.

Our approach to using the Web - which provides a fairly sophisticated, on-demand, 3D visualization of the anatomical structure by using a distributed system of Unix compute servers to provide the required computational capability (see [1] and [3]) - lead to the Virtual Frog Dissection Kit (http://www-itg.lbl.gov/vfrog. This approach was a direct outgrowth of our DOE/ER/MICS funded work in high-speed distributed computing systems.

The Virtual Dissection Kit allows various types of interaction with the 3D frog anatomy, including full 3D interaction with the various anatomical systems, both singly and in their correct spatial relationships as in an intact frog (something difficult to do during laboratory dissection), on-demand generation of movies of rotating views of the anatomy, etc.

This approach has been very successful. In the past approximately 18 months, the Dissection Kit has been used more than a million and a half times, by people in more than a hundred different countries. About 50% of the users are from educational institutions, and informal surveys, and user feedback, indicates that a significant fraction of those are in K-12 schools.

The Web pages that are the Dissection Kit interface are available in Spanish, German, Dutch, French, Czech, Italian, and Portuguese, and we know of Chinese and Japanese versions. (Most of the translations were provided by enthusiastic users in those countries.) (We are frequently asked "can we copy your images so that we can put them on our own Web server or on CDROM". Our stock answer is:

> *The Interactive Frog Dissection kit is not a set of files, and therefore cannot be distributed on CDROM.*
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> *The Web interface for the Frog sends instruction to programs running on large Unix servers in order to generate the images, on-demand, based on the user input and interaction.*
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> *The Dissection Kit is an example of interactive 3D visualization that requires fairly large backend server systems (e.g. at least several large Unix workstations) to do the rendering (i.e., image creation from the large 3D volume data set that represents the frog.).*
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> *The beauty of using the Web publishing techniques as the user interface is that any Web browser can interact with and view the 3D model, but large systems are required in the background to make it all work.*
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> *I refer you to http://www-itg.lbl.gov/vfrog/WWW.94.paper.html for more information.*

Results

Every indication, both from user feedback and from the students and teachers who worked on the project, is that this approach is an effective way to present complex biological structure information for primary and secondary education. (The original idea of also using the material to teach 3D computer visualization has turned out to be suitable mostly at the college level.)

Issues

Our experience with the preparation and presentation of the data lead us to believe that there were many ways that laboratory collection and analysis of the original data could be improved to increase the effectiveness of the presentation. Our original intent, reinforced by the success of the frog, was to produce 3D data sets for many different types of plants and animals and to make this material available to high school and college instructors. However, various circumstances - not least of which was that this work was not very close to our core program - have not permitted us to pursue this goal.

The attempts to use high resolution MRI failed because of (in the opinion of the MRI experts, and to every ones surprise) the high concentrations of iron in the pigments of the frog skin. (However,

several high resolution MRI data sets of plants were produced.) Subsequently we produced an approximately 250 micron resolution volume data set by mechanical sectioning with a cryotome, and imaging of the individual sections. (See http://www-itg.lbl.gov/ITG.hm.pg.docs/Whole.Frog/Whole.Frog.html .)

Conclusions

We still believe strongly that the approach is useful and effective, and have actively encouraged others to pursue this approach. However, not many have done so, primarily because to be successful requires a strongly interdisciplinary team of laboratory biologists, anatomists, and imaging and computer graphics experts, in order to accomplish all of the required tasks to produce a successful, realistic, and usable interactive presentation of complex biological structures.

References:

[1] "Virtual Frog Dissection: Interactive 3D Graphics Via the Web." David Robertson, William Johnston, and Wing Nip. Presented at The Second International WWW Conference '94: Mosaic and the Web, Chicago, IL (1994). http://www-itg.lbl.gov/vfrog/WWW.94.paper.html

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[3] "Using the World Wide Web to Provide a Platform Independent Interface to High Performance Computing". David W. Robertson and William E. Johnston. COMPCON '95: Technologies for the Information Superhighway. San Francisco, CA (1995)

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[6] "The Visible Human Project." NIH.
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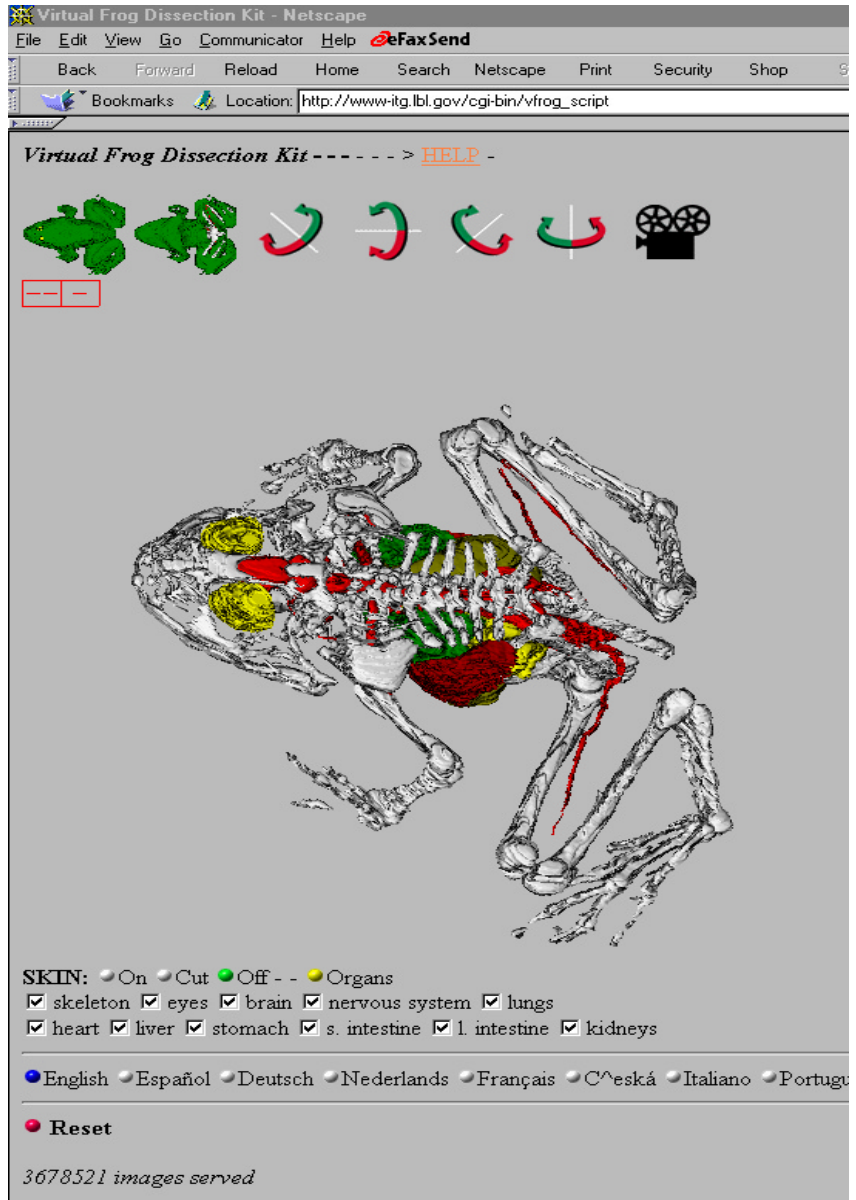# and the Success of the Whole Frog Project

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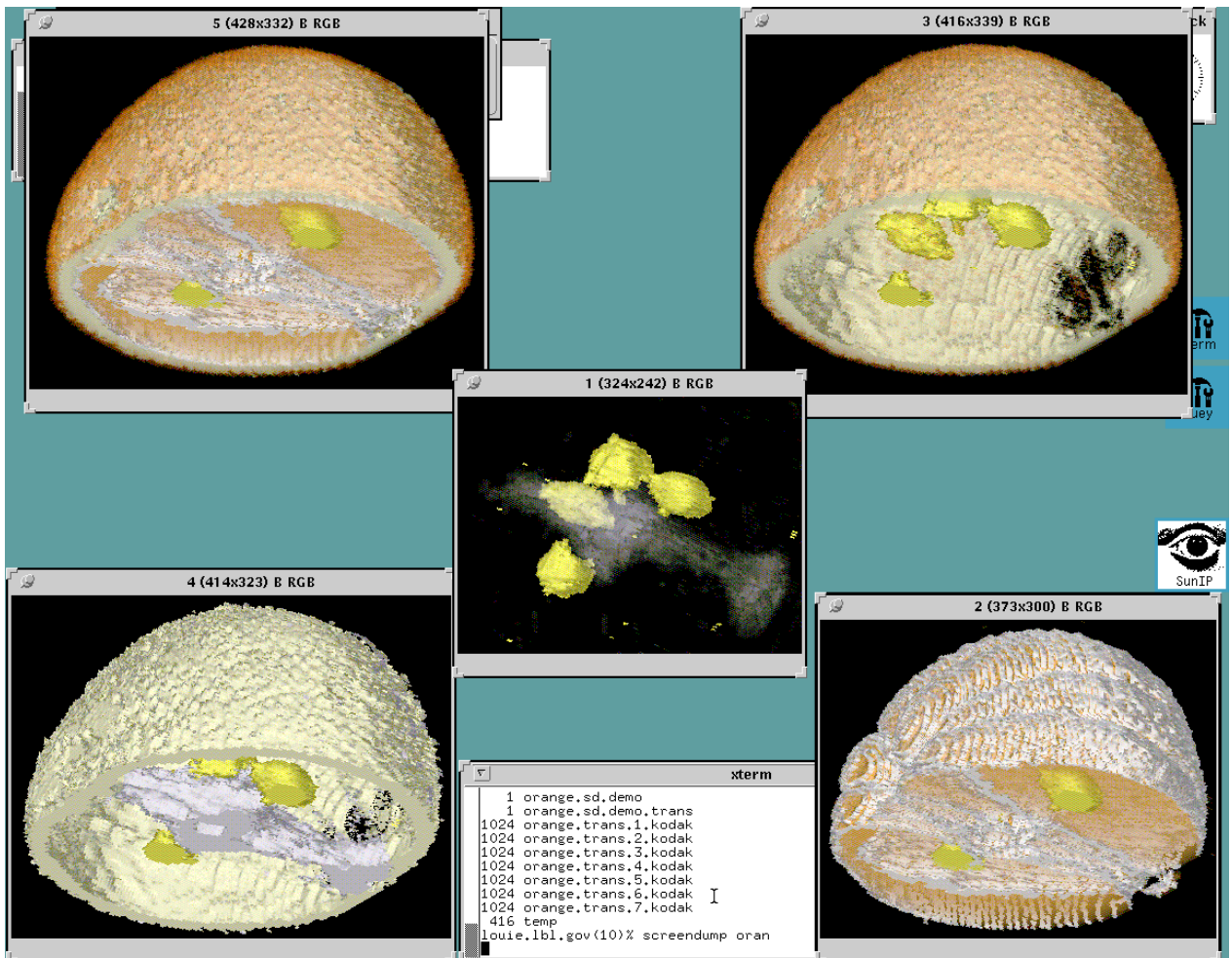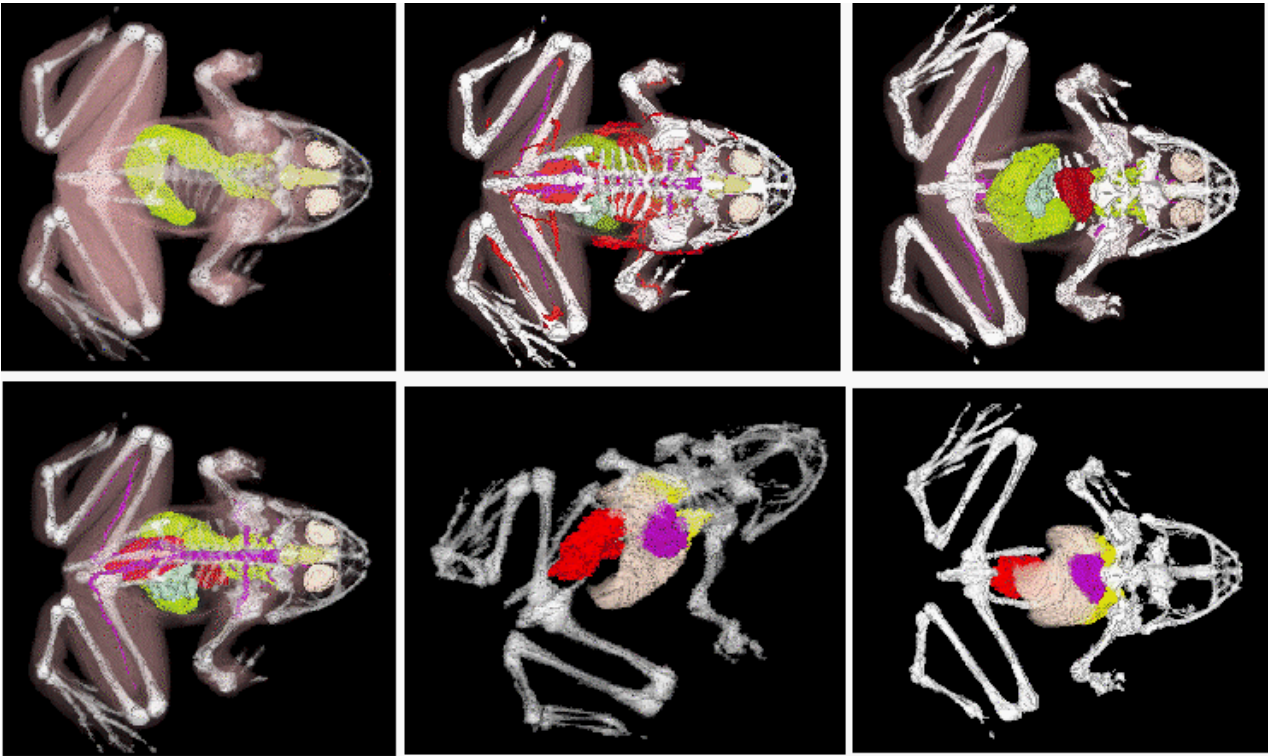
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